5bit guided-wave SNS transfer characteristics

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The experimental transfer characteristics of a three-channel 5bit symmetrical number system (SNS) guided-wave ADC are reported. The SNS preprocessing provides resolution greater than 1bit per interferometer. The results serve to demonstrate the feasibility of the SNS ADC concept.

Introduction: High performance analogue-to-digital converters employ a parallel configuration of analogue folding circuits that symmetrically fold the input signal prior to quantisation by high speed comparators (analogue preprocessing) [1, 2]. Recently, a new preprocessing approach was identified that can easily be incorporated into established techniques to provide an enhanced resolution capability with fewer comparators loaded in parallel. The technique is based on preprocessing the analogue signal with a symmetrical number system (SNS). The SNS decomposes the analogue amplitude analyser operation into a number of parallel suboperations (pairwise relatively prime moduli m), which are of smaller computational complexity [3, 4]. Each suboperation (or channel) symmetrically folds the analogue signal with a folding period equal to the modulus. A small comparator ladder then amplitude analyses each folded output waveform. The comparator states within each channel are recombined in a logic block to recover the SNS encoded input analogue signal.

Since the SNS folding waveform is symmetrical, ambiguities exist within each folding period or modulus. Consequently, the dynamic range of the SNS preprocessing depends on the SNS definition and the manner in which the channels are recombined. A new definition that considerably extends the dynamic range of the SNS preprocessing is given in [5]. In this definition, each channel symmetrically folds the analogue signal with a folding period equal to twice the modulus (i.e. $2m_i$). Each channel requires $m_i - 1$ comparators. The resulting comparator states within each folding period are $\bar{x}_m = [0, 1, \ldots, m-1, m-1, \ldots, 1, 0]$. For N channels, the corresponding dynamic range is $M = \Pi_{i=1}^{N} m_i$, which is considerably larger than that given in [3, 4]. An analytical comparison with these previous schemes shows that $\bar{x}_m$ is optimum [6].

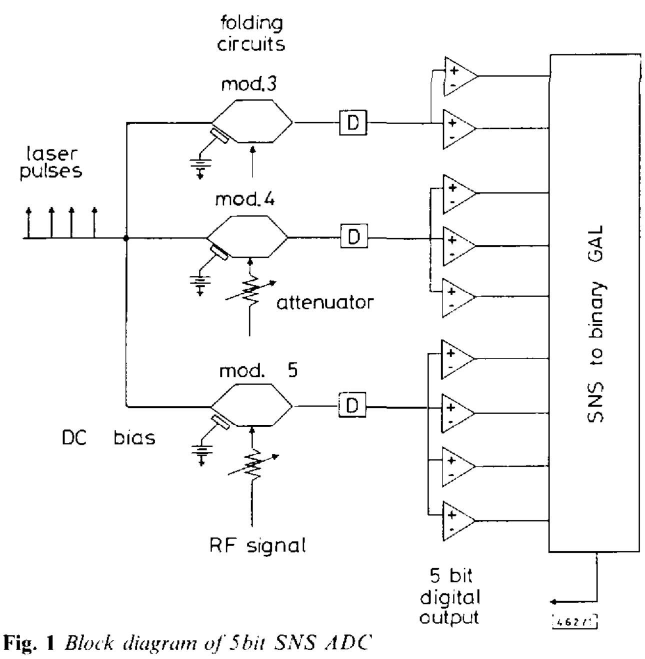

Fig. 1 *Block diagram of 5bit SNS ADC*

Guided-wave SNS ADC: In an integrated optical guided-wave SNS ADC, N Mach-Zehnder interferometers are used to fold the analogue waveform. The block diagram of a 5bit three-channel SNS ADC is shown in Fig. 1. The RF analogue signal to be digitised is applied in parallel to each interferometer and is sampled using a series of laser pulses. The important interferometer parameter to be considered is the maximum analogue voltage V_{max} that may be applied and still give a symmetrically folded waveform. Knowing V_{max}, the maximum number of folds available from the interferometer is

$$F = \frac{V_{max}}{V_\pi} \quad (1)$$

where V_π is half the folding period. In the optimum SNS ADC, a complete fold is $2m_i$ states. Therefore, the largest number of folds required in a B bit SNS ADC is

$$F_{req} = \frac{2^B - 1}{2m_{min}} < \frac{V_{max}}{V_\pi} \quad (2)$$

where m_{min} is the smallest modulus in the SNS system. The LSB code width is $V_\pi/2m_i$.

Each of the three identical $LiNbO_3$ interferometers in the 5bit ADC had a V_π = 2.25V. The V_{max} was determined to be V_{max} = 12V (±12V). The number of symmetrical folds from eqn. 1 is 5.3. From eqn. 2, the minimum modulus is $m_{min} = 3$. The resulting 5bit system is then $m_1 = 3$, $m_2 = 4$ and $m_3 = 5$ with an $LSB = 0.375$V. To provide the larger folding periods for the $m_2 = 4$ and $m_3 = 5$ channels, the analogue signal is attenuated before being applied to each interferometer. To properly align (or phase) each channel, a DC bias is applied to each interferometer. The properly folded and aligned waveforms are shown in Fig. 2. At the left edge of the ADC range, the folded waveforms are in nominal alignment. Furthermore, the 5.3 folds are used within the minimum modulus. The 5bit design requires a total of nine comparators (AD 9698).

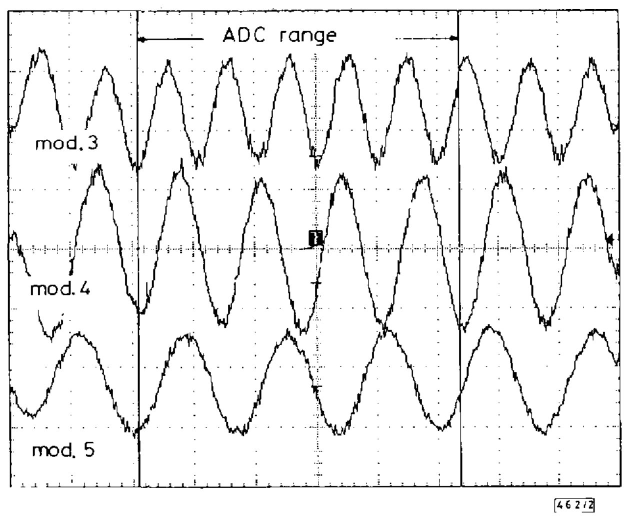

Fig. 2 *Interferometer folding waveforms*

Channel 1: 50.0mVΩ
Channel 2: 50.0mVΩ
Channel 3: 100.0mVΩ

The SNS-to-decimal mapping function was instrumented using a single Lattice 22V10-15 generic array logic (GAL) device. The analogue signal at the interferometers was sampled using a BCP-410 laser transmitter (sampling pulse width = 40ns).

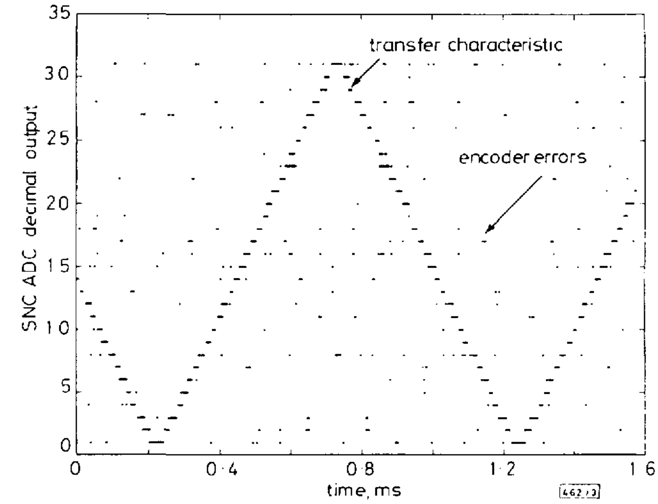

Fig. 3 *SNS ADC transfer characteristic with 1kHz triangular input*

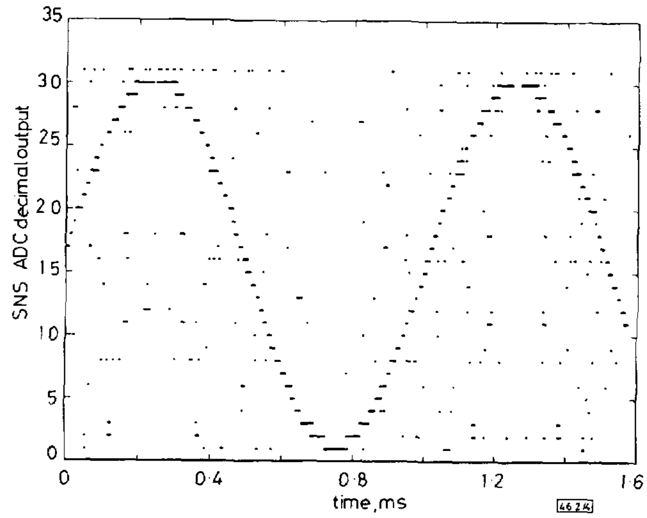

Fig. 4 *SNS ADC transfer characteristic with 1kHz sine-wave input*

To demonstrate the SNS ADC transfer characteristics, a 1kHz triangular waveform was applied. The SNS ADC decimal output is shown in Fig. 3. Note the 32 distinct quantisation levels. A 1kHz sine waveform was also applied. Fig. 4 shows the corresponding transfer characteristic for this input. These results serve to demonstrate the feasibility of the optical SNS ADC concept.

Discussion: We have reported the experimental transfer characteristics of a 5bit integrated optical guided-wave SNS ADC which requires only nine comparators. It can be seen in Figs. 3 and 4 that a small amount of noise is present in the ADC output. This noise is due to encoding errors that result when an input voltage lies at a code transition point [4–6]. By using a few additional comparators in the smallest channel and computing the parity, small bands may be set up about these transition points and the errors easily discarded. This approach is currently being investigated for a 14bit system, the results of which will be reported at a later date.

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